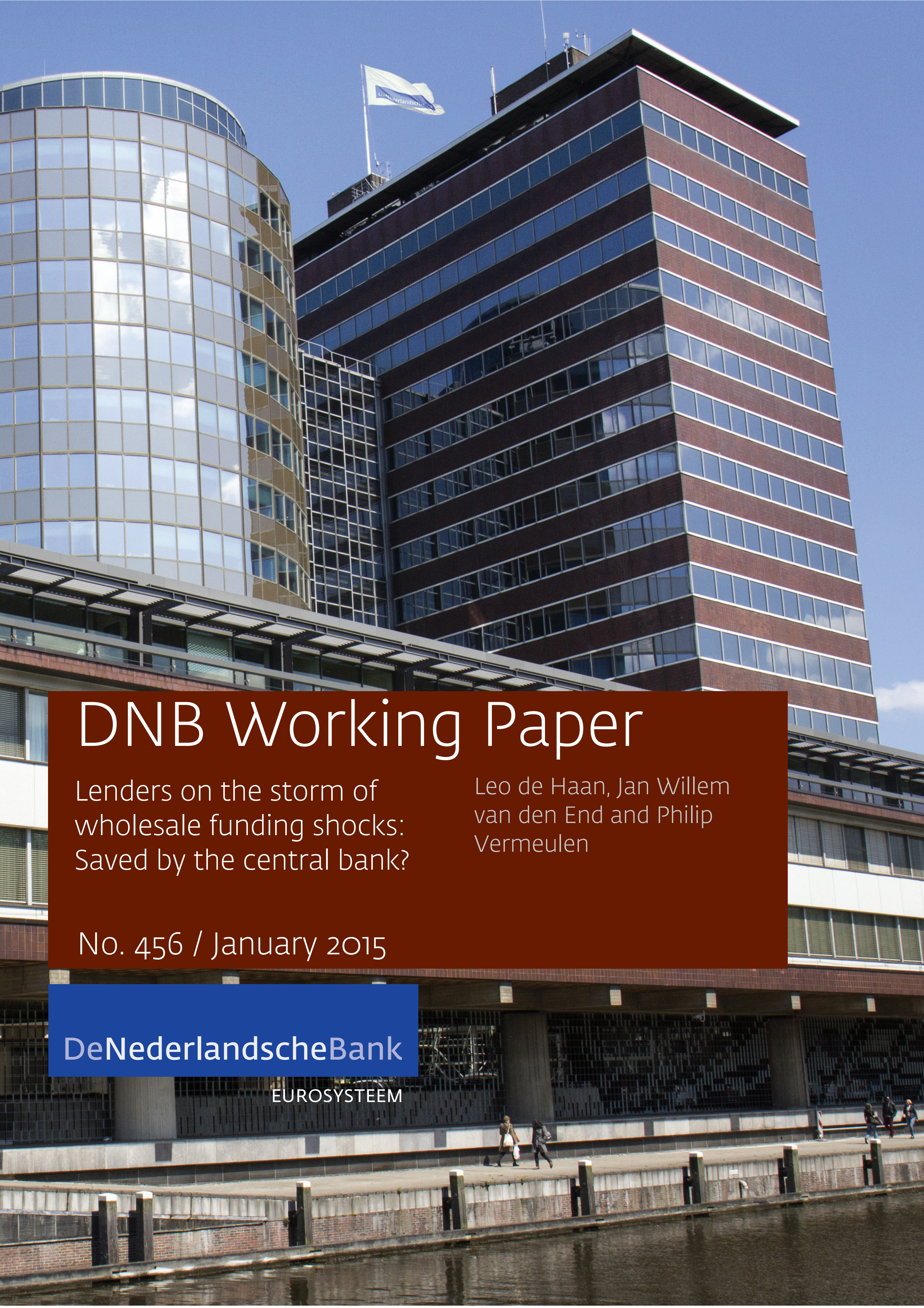

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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Lenders on the storm of wholesale funding shocks: Saved by the central bank? *

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Abstract

We provide empirical evidence on banks' responses to shocks in wholesale funding, using data of 181 euro area banks over the period August 2007 to June 2013. Banks' adjustments of loan volumes and lending rates in response to funding liquidity shocks are analysed in a panel VAR framework. The results show that shocks in the securities and interbank markets have significant effects on loan rates and credit supply, particularly of banks in stressed countries. Central bank liquidity has mitigated this effect. Lending to non-financial corporations is more sensitive to wholesale funding shocks than lending to households. Moreover, bank characteristics matter for monetary transmission: loan growth of large banks that are typically more dependent on wholesale funding and of banks with large exposure to government bonds shows relatively stronger responses to wholesale funding shocks.

Keywords: banking/financial intermediation, financial crisis.
JEL classifications: G21, G32.

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1. Introduction

The purpose of this paper is to add to a better understanding of the risks posed by banks' reliance on wholesale funding. Wholesale funding refers to the use of deposits and other liabilities from institutions such as banks, pension funds, money market mutual funds and other financial intermediaries. When a bank relies on short-term wholesale funds to support long-term illiquid assets, it becomes vulnerable to runs by wholesale creditors. This risk manifested itself since the start of the financial crisis in 2007, when banks were confronted with severe strains in funding liquidity. Interbank funding dried up, causing interbank money market spreads to soar (Figure 1). After the failure of Lehman Brothers in 2008, this was soon followed by the drying up of wholesale funding markets. The functioning of those markets was severely undermined by increased counterparty risk and a shortage of high-quality collateral. From 2011 onward, when the financial crisis was followed by the sovereign debt crisis, banks in peripheral euro area countries even faced an accelerating outflow of retail funding, normally one of the most stable funding sources. Those funding strains forced banks to adjust their balance sheets in various ways. They responded by reducing maturity mismatches, switching to alternative sources of finance and by deleveraging. This activated the so-called liquidity channel of financial transmission through which funding liquidity shocks are propagated to bank lending and the real economy (BCBS, 2011). Our paper provides new empirical insights into the working of the liquidity channel.

[insert Figure 1]

The Eurosystem has reacted to banks' funding strains by various measures. Refinancing operations have been extended in terms of maturity, size and conditions. This enabled banks to obtain liquidity from the central bank at fixed rate at full allotment. In particular the two very long-term refinancing operations (VLTROs) of end-2011 and early 2012 have relieved the funding strains. While banks in stressed countries benefitted most from these measures, banks in non-stressed euro countries used the central bank deposit facility to a larger extent. By this, the Eurosystem took over part of banks' intermediation function through the money market. Only recently, since 2013, the intermediary role of the Eurosystem has gradually declined owing to repayments by banks on VLTROs. The targetted long-term refinancing operations (TLTROs), launched in 2014, has increased the ECB's outstanding loans again from September 2014 onwards.

This paper contributes to the growing literature on how banks adjust to funding liquidity shocks, using a unique, new set of monthly data of 181 euro area banks. Balance sheet data are combined with data of loan rates and data of central bank borrowing by individual banks. This unique combination of data and its high frequency allow us to address two research questions: i) how did banks with different characteristics respond to wholesale funding shocks in terms of adjustments of lending volumes and loan rates? ii) to what extent has the extension of central bank refinancing operations mitigated these volume and price effects?

Banks' behavioural responses to funding liquidity shocks have been addressed in the recent literature on bank liquidity, both empirically and theoretically (see Section 2). However, this research is mostly based on data of US banks, while our paper covers a large sample of euro area banks. For the euro area, insight in the transmission of funding shocks is highly relevant given its bank-based financial system. Moreover, the responses of banks in the euro area are likely to be more heterogeneous than in the US, given different levels of financial integration and exposures to sovereign risk. Another contribution of our paper is that we allow for two-way interactions between the asset and liability side while addressing banks' responses to funding stress. The dynamic interactions between assets and liabilities are described in the context of a financial flow model (see e.g. Berg (2012)). In such a model deposits generate loans, since an increase of deposit funding improves the liquidity position of banks and thereby their capacity to extend loans (loans being the monetary counterpart of deposits). Vice versa, bank loans create deposits, since the funds received by a borrower will end up in a deposit, either in the account of the borrower or in the account of his counterparty who receives a payment. However, this does not mean that it is a closed system in which loan growth equals deposit growth by definition. First, a loan from one bank may be deposited at another bank. Second, banks can use alternative (i.e., wholesale) funding sources for their lending activities, while firms and households can invest in assets other than deposits. Third, there can also be leakages from the non-financial to the financial sector or to institutions abroad.

To capture the dynamics between the assets and liabilities of banks, we use a multi-equation framework, which relates bank funding variables to bank assets and bank loan interest rates - instead of a single-equation framework. A multi-equation approach has been used before. Spindt and Tarfan (1980), for example, model US banks' liquid assets and liabilities as a system of equations. In their model, liabilities are qualified as (weakly) exogenous and assets as endogenous, based on the idea that banks can determine their investment and lending strategies, while the availability of funding is predominantly given. We adopt similar assumptions in this paper. However, there are several differences between their and our approach. Spindt and Tarfan estimate separate models for five large US money-center banks and then average the coefficients. In contrast, we estimate a multi-equation model while pooling our sample of banks, so that the model describes the banks' average behaviour. Furthermore, we use a panel Vector Auto-Regressive (p-VAR) model, which takes into account the heterogeneity between individual banks by allowing for fixed effects. A useful feature of VAR models is that they can generate orthogonalized impulse-response functions, identifying the impact of an isolated shock in one variable to all other variables in the system. The VAR model is estimated using monthly data of 181 European banks in 17 euro area countries over the period August 2007 to June 2013. The sample accounts for 55% of total euro area main bank assets and 56% of total bank loans. It covers a diverse set of banks, ranging from large and complex institutions to small regional banks.

In the analysis we focus on the effects of shocks in wholesale funding, in particular interbank funding (both secured and unsecured) and security issuance by banks. We also include interbank money market spreads at the country level to control for wholesale funding costs. The adjustments of bank lending and loan rates in response to funding shocks are simulated while controlling for credit demand, which is proxied by an economic indicator. By including this indicator, next to volumes and prices of loans, the model captures both credit demand and credit supply effects. Demand effects are driven by the need for and price of bank credit. Adjustments of loan rates may result from changes in funding costs, which banks pass on to their customers, or from reduced access to funding, which forces banks to raise loan rates. As a consequence, the *demand* for credit may fall according to the *bank interest rate channel* of financial transmission (Angeloni et al., 2003). On the other hand, credit *supply* effects may originate from changes in available funding volumes. When banks are rationed in the funding market, they have fewer means to support their asset side activities. As a consequence, they may curtail lending according to the *liquidity channel* of financial transmission. This channel highlights the importance of liquidity risk in influencing the traditional bank lending channel, which explains changes in loan supply from changes in monetary policy rates (BCBS, 2011). We investigate to what extent bank reactions differ across groups of banks (e.g. groupings according to size, government bond holdings, central bank dependence) and across countries, in particular between stressed and non-stressed countries ('stressed' in the sense of relative vulnerability during the sovereign debt crisis). The bank capital channel is beyond the scope of our analysis and is left for future research.

We find that banks respond to wholesale funding shocks in several ways. Through the liquidity channel, household and corporate loan growth rates decline and interest rates increase in response to a fall in wholesale funding growth (and vice versa), being either interbank funding or securities issuance. Corporate lending growth and interest rates are more sensitive to wholesale funding conditions than household lending growth and interest rates. The intuition behind this is that a wholesale funding shock forces banks to adjust their asset side quickly, both in terms of size and in terms of risk. Banks realise this adjustment by changing their corporate lending rather than their household lending, since in general the former has a shorter maturity and a higher risk profile than the latter. The response of loan growth to a shock in securities funding is greater for banks in stressed countries and for banks with high central bank borrowing, compared to banks in non-stressed countries and banks with low central bank borrowing. However, differences in lending responses to wholesale funding shocks between high and low borrowing banks are not statistically significant, particularly not with regard to shocks in interbank funding, which was mostly substituted by central bank funding. This result indicates that central bank funding mitigated the impact of wholesale funding shocks on bank lending. Bank size is a determining factor for the transmission of wholesale funding shocks. Lending by large banks that are typically more dependent on wholesale funding, responds more strongly to a shock in securities funding compared to lending by small banks. Likewise, lending by banks with greater exposures to government bonds responds stronger than lending by banks with limited government exposure.

All in all, the results show that funding liquidity risk is a determining factor in monetary transmission and that bank characteristics determine the extent to which this channel is at work. Moreover, there is some evidence that central bank borrowing shielded bank lending from shocks in wholesale funding markets to some extent. From this we conclude that the unconventional monetary policy measures of the Eurosystem, notably the unlimited provision of liquidity to banks, has contributed to support private credit growth.

The structure of the paper is as follows. Section 2 reviews some related literature, while Section 3 introduces the model. Section 4 describes the data and some stylized facts. Section 5 discusses the results and Section 6 presents the outcomes for various subsamples. Section 7 concludes.

2. Related studies

Since the financial crisis, a growing literature has addressed the transmission of bank funding shocks to bank lending. We discuss several studies, without claiming to be complete.

Concerning the response of bank lending to funding liquidity shocks, the theoretical study of Diamond and Rajan (2005) stresses the interaction and reinforcing effects of banks' liquidity shortages and solvency problems. They explain how aggregate liquidity shortages can emerge and force banks to prematurely restructure loans that otherwise would generate liquidity, which can restrain future lending. Empirically, the response of bank lending to funding shocks has been examined mostly by means of single equation models. For example, Ivashina and Scharfstein (2010) find that a greater volatility of deposits and more frequent and greater draws on committed credit lines prompt US banks to reduce lending. Cornett et al. (2011) report that US banks with more stable funding sources were better able to continue lending during the crisis. The results of Damar et al. (2014) suggest that wholesale funding by Canadian banks is primarily allocated to large corporate loans and that adverse shocks on wholesale funding markets most likely affect businesses that receive large loans.

Several studies find that the strength of banks' balance sheets influences the transmission of funding shocks to lending. Kapan and Minoiu (2013) conclude that the sensitivity of bank lending to market liquidity shocks depends on the strength of banks' balance sheets. Based on single equation regressions with micro-data of syndicated loans of more than 800 banks in 55 countries they find that banks that were more dependent on market funding and had lower structural liquidity, reduced the supply of credit more than other banks. Higher and better-quality capital mitigates this effect. Dinger and Craig (2013) model the reverse causality, running from deposits to loans, for the largest US banks. It turns out that banks facing high uncertainty in loan volumes react to loan shocks by mainly adjusting their wholesale funding while those facing lower volatility rather modify retail deposit volumes.

Recently, some empirical studies have focused on financial transmission in the euro area. Ciccarelli et al. (2013) estimate a VAR model using micro data on euro area banks, in particular data on credit conditions and bank lending standards. They show that monetary transmission is time-varying and influenced by the financial fragility of the sovereigns, banks, firms and households. The amplification mechanism is explained by the credit channel, covering both the bank lending and the non-financial borrower balance-sheet channels. The results suggest that the bank-lending channel has been to a large extent neutralized by the ECB non-standard monetary policy interventions. Giannone et al. (2012) analyse the impact on the macroeconomy of the ECB's non-standard monetary policy implemented in the aftermath of the collapse of Lehman Brothers in 2008, based on aggregate bank data. Their simulations of a VAR model suggest that bank loans to households and, in particular, to non-financial corporations are higher than would have been the case without the ECB interventions. Since their study covers data up to 2011, it does not include the effects of VLTROs. Bijsterbosch and Falagiarday (2014) model credit supply effects in euro area countries with a time-varying parameter VAR. The results show that credit supply shocks have been a key driver of business cycle fluctuations in many euro area countries, especially in the recent crisis, while cross-country heterogeneity increased strongly. Al-Eyd and Berkmen (2013) model the bank interest rate channel of monetary transmission for the euro area with country-specific lending rates. They find that funding costs – measured by bank equity prices and deposit rates – determine bank lending rates, next to credit risk and bank leverage.

De Haan and Van den End (2013) model Dutch banks' responses to funding liquidity shocks. They analyse three types of adjustment on the asset side of the bank balance sheet, i.e. adjustments of lending, liquidity hoarding, and fire sales. The dynamics of the bank reactions are modelled in a panel VAR framework. They report that in response to funding shocks banks reduce lending, especially wholesale lending. They also find evidence of liquidity hoarding and fire sales of assets. The latter are more likely being triggered by liquidity constraints rather than by solvency constraints.

This paper contributes to this growing literature on how European banks adjust to funding liquidity shocks, using a unique, new set of data of 181 euro area banks. It differs from other studies by capturing the dynamics between assets, liabilities and loan interest rates of individual banks in a multi-equation framework, while taking into account different bank characteristics. We also contribute to the literature by providing new empirical evidence on the effects of central bank liquidity supply on bank responses to wholesale funding shocks.

3. Model

Following De Haan and Van den End (2013), we use a panel-VAR model, which treats all variables in the system as endogenous and allows for unobserved individual heterogeneity by including fixed effects:

$$\begin{bmatrix} X_t \\ Y_{it} \end{bmatrix} = A_i + B(L) \begin{bmatrix} X_t \\ Y_{it} \end{bmatrix} + \varepsilon_{it} \qquad (1)$$

where X_t is a vector containing an indicator for credit demand and the money market swap spread for each month t. Y_{it} is a vector of balance sheet and loan rate variables for each bank i and month t. A_i is a matrix of bank-specific fixed effects, $B(L)$ is a matrix polynomial in the lag operator whose order is 2.[1] ε_{it} is the error term. The coefficients of the p-VAR model are estimated by system Generalised Method of Moments (GMM), using lags of the model variables as instruments.[2] GMM is widely used in the absence of strictly exogenous variables or instruments; see for instance Doytch and Uctum (2011). System GMM has one set of instruments to deal with the endogeneity of regressors and another set to deal with the correlation between the lagged dependent variables and the error terms. The fixed effects are eliminated by expressing all variables as deviation from their means. Since the fixed effects are correlated with the regressors as a result of the inclusion of lags of the dependent variables, ordinary mean-differencing (i.e. expressing all variables as deviations from their full sample period means), as commonly used to eliminate fixed effects, would create biased coefficients. To avoid this problem, forward mean-differencing, also known as ‘Helmert' transformation', is used instead (cf. Arellano and Bover, 1995). This procedure removes only the forward mean, i.e. the mean of all future observations available in the sample and preserves the orthogonality between transformed variables and lagged regressors, so that the lagged regressors can be used as valid instruments for estimating the coefficients by system GMM.

[1] We experimented with different lag lengths and it turned out that the number of lags did not make a significant difference in the impulse responses.

The main aim is to identify banks' responses in lending volumes and lending rates to shocks in wholesale funding. We distinguish two sources of wholesale funding: (1) interbank borrowing (*MFI*) and (2) securities issued (*S_is*). Interbank borrowing excludes funding from the Eurosystem. For bank lending, we consider both lending to households (*L_hh*) and lending to non-financial corporations (*L_nfc*). Likewise, for lending rates we distinguish rates on new loans to households (*R_lhh*) and rates on new loans to non-financial corporations (*R_lnfc*). As control variables we include the spread on the money market swap rate (*Spread*) and the Economic Sentiment Indicator (*ESI*) for each country in the sample. *Spread* represents the cost of unsecured interbank funding; since it is not available for individual banks and countries we use the euro area average. *ESI* is a composite indicator made up of five sectoral confidence indicators at the country level, which controls for credit demand. This economic indicator is highly correlated with quarterly GDP growth (see Figure 2), and is available at a monthly frequency.[3] Since the business cycle is a main determinant for corporate defaults, the *ESI* implicitly also reflects credit risk. Appendix A shows the definitions of the variables.

[insert Figure 2]

To keep the p-VAR models estimable, we restrict the number of variables per p-VAR model to five and estimate four separate models. Each model includes one wholesale funding variable (*MFI* or *S_is*) and one lending variable (*L_hh or L_nfc),* together with the corresponding lending rate (*R_lhh* or *R_lnfc*). All models contain the two control variables, *Spread* and *ESI*. Each model is used to analyse the effect of a particular wholesale funding shock on a particular lending volume and rate. To retain stationarity we include the wholesale funding variables and lending variables in terms of month-on month growth rates. Interest rates, the spread and the ESI, typically being stationary, are included in levels. Moreover, the forward mean-differencing transformation contributes to the stationarity of the model variables. Panel unit root tests indicate that all series are stationary.[4]

To examine banks' responses to funding liquidity shocks, we use impulse-response functions that are derived from the p-VAR models. The shocks are orthogonalized, so that the response of one variable to a shock in another variable can be interpreted as the reaction of the former variable to the innovations in the latter, while holding all other shocks equal to zero. By this we can isolate credit supply from credit demand effects. To orthogonalize the shocks it is necessary to decompose the

[2] For more details we refer to Love and Zicchino (2006), whose Stata code we gratefully used for the estimation.
[3] The use of real GDP growth as a control variable for loan demand is common in e.g. the extensive empirical literature on the credit channel (e.g. Kashyap and Stein, 2000; De Haan, 2003), where bank loan supply effects are examined. Since monthly data of GDP growth are not available, we use the economic sentiment indicator as a proxy.

residuals. The decomposition is conducted by imposing a particular ordering of the variables in the system and attributing any correlation between the residuals of any two elements to the variable that comes first in the ordering. This procedure is known as the Choleski decomposition. The identifying assumption is that variables that come earlier in the ordering affect the following variables contemporaneously, as well as with lags, while the variables that come later affect the previous variables only with lags. In other words, the variables that appear earlier in the ordering are more exogenous than the ones that appear later (or, more formally, in the short run the former are weakly exogenous with respect to the latter). We perform robustness checks to test the sensitivity of the outcomes for changes in the ordering of the variables in Section 6.4.

For our four model specifications, we generally adopt the following principles with respect to the ordering of the variables. The economic indicator ESI (reflecting overall credit demand in a particular country) comes first in the ordering, assuming that it is the most exogenous variable for the individual bank. Second, we assume that shocks in the availability and cost of funding have an immediate effect on the asset side of the balance sheet (credit supply and loan rate) and that funding conditions respond to asset side shocks with a lag. This assumption reflects the fact that funding depends on market conditions that are often outside the banks' direct control, while banks' asset management in principle is at their own discretion.[5] In other words, the liability side (costs and volumes) is more exogenous than the asset side and therefore liability items appear earlier in the ordering. Third, we assume that wholesale variables (both rates and volumes) respond more quickly than retail items. This takes into account that wholesale instruments usually have shorter maturities than retail instruments and therefore can be more easily adjusted. Based on these assumptions, *Spread* is ordered second in the models, followed by the wholesale funding volumes (*MFI* or *S_is*) as a third variable, while the lending rate (*R_lhh* or *R_lnfc*) and lending volume (*L_hh or L_nfc*) are ordered as fourth and last variable, respectively.

Since the impulse-response functions are constructed from the model's estimated coefficients, the latter's standard errors need to be taken into account. We calculate the standard errors and generate confidence intervals of the impulse response functions using Monte Carlo simulations. This is conducted by taking random draws of the model's coefficients, using the estimated coefficients and their variance–covariance matrix. We take 200 draws. The 5th and 95th percentiles of the resulting distribution are used for the 90% confidence intervals of the impulse-responses.

[4] According to Levin-Lin-Chu unit-root test (excluding panel means and time trends) unit roots for all series can be rejected. Results are available on request.
[5] Access to funding may depend on banks' risk management strategies as well, but most likely with a lag.

4. Data

The data source of the bank variables is the ECB's individual balance sheet and interest rates statistics (IBSI and IMIR). This new and unique data source contains end-of-month data on assets and liabilities (IBSI) and deposit and loan rates (IMIR) for individual monetary financial institutions (including branches and subsidiaries of foreign banks that have a significant share in the domestic banking sector). Balance sheet data are available for the period August 2007 to June 2013 and interest rate data from August 2007 up to June 2012.

The IBSI dataset contains around 250 monetary financial institutions (MFIs). Some of these are highly specialized (such as import-export financing) and cannot be categorised as regular banks that deal with both non-financial corporations and households. As we investigate the effect on lending volumes to non-financial corporations and households, we exclude all specialised financial institutions. Effectively, we remove MFIs that have no lending to either non-financial corporations or households (i.e. lending volume is always zero). We also exclude MFIs that have no deposits from either non-financial corporations or households (this excludes pure investment banks). This way we create a more homogeneous dataset of MFIs with a traditional banking function, i.e. deposit taking and lending. This reduces the dataset to 193 MFIs which we call 'banks'. To correct for structural breaks, we further exclude 12 banks that show an extreme change of total assets within the sample period.[6] Such extreme changes are most likely due to bank restructurings, mergers etc. This way we avoid that major changes of the banking institutions influence the results. Our final dataset contains 181 banks in 17 euro area countries. Our variables of interest are summed up and defined in Appendix A. Next to the sample of 181 banks, we construct sub-samples of banks according to country groupings (stressed versus non-stressed countries) and groups of banks (small versus large banks, banks with low versus high government bond holdings, and banks with high versus low central bank borrowing). The group of stressed countries consists of Greece, Italy, Ireland, Portugal, Spain and Cyprus, as these countries were most severely hit by the sovereign debt crisis.

Table 1 provides summary statistics for balance sheet items, for the full sample as well as for sub-samples. An average bank in the sample is almost equally dependent on retail and wholesale funding. Household and corporate deposits on the one hand, and borrowing from MFIs (excluding the Eurosystem[7]) and securities issued on the other hand, both equal approximately one third of total assets (Table 1). Among them, borrowing from MFIs (excluding the Eurosystem) or securities

[6] An extreme change is defined as the 0.1% tail of the distribution of changes for all banks. Defined this way, a major change is a month on month increase or decrease of the total balance sheet larger than 75 percent.

issuance are approximately equally important (17% versus 15% of main assets). Note however that these averages mask large variations across banks and time. The standard deviation of these variables is quite large. Capital and reserves are on average equal to 7% of main assets[8], with a standard deviation of 5 percentage points. The median bank borrows very little from the Eurosystem, i.e. only 0.2% of main assets (this information has been obtained from another internal ECB data source). The average is however much higher at 3% and the standard deviation is even larger at 5 percentage points. The asset side of the balance sheet is dominated by loans to households (25% of main assets on average), non-financial corporate borrowers (21%) and to other MFIs (16%). On average 6% of the balance sheet consists of euro area government securities.

[insert Table 1]

Table 2 shows the summary statistics of the variables used in the VAR models. The average month on month growth rates of lending to households and to non-financial corporate borrowers is 0.14% and 0.31%, respectively. Month on month rates are quite volatile. The respective standard deviations are 2.70 percentage points and 3.94 percentage points. Over the sample period, average month on month growth rates of securities issued and borrowing from MFIs are negative (-0.68% and -0.32% respectively.) The growth rates of these wholesale funding types are much more volatile than lending growth rates. The growth rate of securities has a standard deviation of 7.06 percentage points. Borrowing from MFIs shows the highest volatility with 21.66%. One possible interpretation is that this high volatility is caused by 'end of day' borrowing due to unforeseen liquidity shocks from other sources (such as in and outflows of deposits).

[insert Table 2]

5. Results

In this section several p-VAR models are estimated to investigate bank lending behaviour following a shock in wholesale funding. We estimate four variants of model (1), in which *ESI* and *Spread* are always in vector *X* and the variables in vector *Y* vary:

$$[ESI \quad Spread \quad S\_is \quad R\_lnfc \quad L\_nfc]' \tag{2}$$

$$[ESI \quad Spread \quad S\_is \quad R\_lhh \quad L\_hh]' \tag{3}$$

[7] Data on borrowing from the Eurosystem, taken from another internal ECB data source, is used to exclude the Eurosystem borrowing from total MFI borrowing.
[8] The dataset contains banks' *main* assets, not all assets.

$[ESI \quad Spread \quad MFI \quad R\_lnfc \quad L\_nfc]'$ (4)

$[ESI \quad Spread \quad MFI \quad R\_lhh \quad L\_hh]'$ (5)

Models 2 and 3 estimate the effect of a shock in securities funding on lending volumes and rates, while models 4 and 5 estimate the effect of a shock in interbank funding. Models 2 and 4 focus on lending to non-financial corporations and models 3 and 5 on household lending. As is usual in VAR-studies, results are presented in the form of impulse responses, including confidence bands. Results are discussed for the full sample of banks (Section 5.1 and 5.2) and sub-samples (Section 6): small versus large banks, banks with low versus high government bond holdings, and banks with high versus low central bank borrowing.[9]

5.1 Liquidity channel: impact on lending volumes

The liquidity channel is first explored by simulating the impact of shocks in wholesale funding volumes on lending. From the impulse responses of the full sample of banks (Figure 3) it appears that both corporate and household loans (*L_nfc* and *L_hh*) react significantly and positively to a shock in wholesale funding (*S_is* and *MFI*). Hence, a decline in the growth of market funding leads to declining lending growth and vice versa. The shock effects only lasts for one month and becomes nil after around 3 months. Lending to non-financial corporations is more sensitive to wholesale funding shocks than lending to households. The 12 month cumulative effect of a 1 standard deviation shock in the growth rate of interbank funding (i.e. a change of 22 percentage points) leads to a decline of 0.19 percentage point in corporate loan growth, compared to a 0.01 percentage point decline in household lending growth (Table 3). This corresponds with findings in related literature, which point at a relative high sensitivity of business loans to wholesale funding (see, for instance, Damar et al., 2014). The intuition behind this is that a wholesale funding shock forces banks to adjust their asset side quickly, both in terms of size and risk. Banks realise this adjustment by changing their corporate lending rather than their household lending, since in general the former has a shorter maturity and a higher risk profile than the latter, which makes it easier to adjust the corporate loan portfolio.

[insert Figure 3 and Table 3]

[9] The third sample-split allows us to analyse the effect of central bank borrowing, which could not be included as a variable in the p-VAR models, because many banks do not borrow from the central bank (complicating log transformation and model estimation as inclusion of central bank borrowing would require dropping another variable from the model to preserve a minimum number of degrees of freedom).

While corporate lending is more sensitive to a shock in interbank funding (*MFI*) than to a shock in securities funding (*S_is*), household lending growth responds more strongly to a shock in securities funding. The cumulative impact over 12 months on household lending growth is five times higher for a shock in securities funding than for a shock in interbank funding (Table 3). This result could be explained by the importance of securitisation for the funding of mortgages, in line with Bonaccorsi di Patti and Sette (2012), who show that Italian banks that heavily relied on securitization curtailed lending more than other banks.

5.2 Bank interest rate channel: impact on lending rates

The bank interest rate channel assumes the pass-through of funding costs to loan interest rates, which affects the demand for loans by households and corporate borrowers. This channel is explored by focusing on the impact of wholesale funding costs on household and corporate lending rates (*R_lnfc* and *R_lhh*) in models 2-5. From the impulse responses for the full sample of banks (Figure 4), it appears that the sensitivity of the corporate lending rate to a shock in the money market swap rate is substantially higher than the corresponding sensitivity of the household lending rate; a 1 standard deviation shock in *Spread* (i.e. 17 basis points) leads to a 0.20 percentage point positive change in *R_lnfc*, compared to a 0.10 percentage point change in *R_lhh*, cumulatively measured over 12 months (Table 3). This underlines the relatively high sensitivity of corporate lending conditions to shocks in wholesale funding markets.

[insert Figure 4]

In most instances, lending rates do not show a significant response to shocks in wholesale funding volumes, except for household loan rates with regard to a shock in securities funding. A 1 standard deviation shock in the growth rate of securities issued (i.e. 7 percentage points change) leads to a 0.21 percentage point negative change in *R_lhh*, measured cumulatively over 12 months (Table 3). The negative sign of the impulse response means that a decrease (increase) in securities funding leads to an increase (decrease) of household lending rates. The effect on loans rates after an interbank funding shock is insignificant. This could be explained by the fact that shocks in the interbank market more likely affect loan rates through the channel of the money market spread than through the channel of interbank funding volumes.

6. Subsamples

6.1 Banks in stressed versus non-stressed countries and the influence of central bank borrowing

To investigate whether the effects of wholesale funding shocks differ between banks in stressed versus non-stressed countries we define a sub-sample of banks located Greece, Italy, Ireland, Portugal, Spain, and Cyprus, which were relatively severely hit by the sovereign debt crisis, versus a sub-sample of banks located in the other euro area countries (which we frame 'non-stressed' countries). The cumulative response of loan growth to a shock in *S_is* is greater in stressed countries than in non-stressed countries, although the difference between both subsamples is not statistically significant[10] (Figure 5). Banks in non-stressed countries are, on average, more dependent on wholesale funding than banks in stressed countries; the combined share of interbank borrowing and securities issued for the former sub-sample is 35% of main assets, compared to 27% for the latter sub-sample (Table 1). However, banks in stressed countries were hit relatively strongly by the turbulence in financial markets; particularly during the 2010-13 sovereign debt crisis, when their access to market funding virtually shut down. The difference between the cumulative effects of a shock in *MFI* on lending growth of banks in stressed versus non-stress countries is negligible, although the confidence bands of the impulse responses do not overlap for all lags, meaning that the difference between the responses of banks in stressed versus non-stressed countries is statistically significant.

[insert Figure 5]

Household lending rates in stressed countries show a relatively strong negative response to a shock in both *S_is* and *MFI* (Figure 6), implying that a fall (rise) in wholesale funding leads to a rise (fall) in the loan rate. Household lending rates in stressed countries change approximately 0.3 to 0.4 percentage points after a 1 standard deviation shock in wholesale funding growth. This response of household loan rates in stressed countries is significantly different from the response of household loan rates in non-stressed countries (Figure 6 shows that the confidence bands of the impulse responses of the two subsamples do not overlap for all lags).

[insert Figure 6]

The responses of lending growth and loan rates in response to wholesale funding shocks also differ between banks that heavily borrowed from the Eurosystem and banks that borrowed little (banks with high (low) Eurosystem funding are banks with an average central bank funding over main assets ratio above (below) the median ratio during the sample period). The growth of lending by banks with a high level of central bank borrowing ("high borrowing banks") shows a stronger response to shocks in *S_is*

[10] The statistical significance is tested by comparing the confidence bands of the impulse responses of the two subsamples, see Figure 5. If the confidence bands overlap for all lags, the impulse responses are not significantly different.

compared to low borrowing banks (Figure 7), although this difference is not statistically significant. The difference between both sub-samples of banks with regard to the effect on lending growth in response to shocks in *MFI* is less obvious. The household lending rate of high borrowing banks shows a relatively strong negative response to a shock in *S_is* (Figure 8), implying that a fall (rise) in securities funding leads to a rise (fall) in the loan rate. This response of household loan rates of high and low borrowing banks is only statistically different in case of a shock in *MFI*.

[insert Figure 7 and 8]

Banks in stressed-countries rely much more on the Eurosystem than banks in non-stressed countries. For the former sub-sample, central bank borrowing is on average 5% of main assets compared to 1% for the latter sub-sample (Table 1).[11] While the effects of wholesale funding shocks on lending by banks in stressed countries and on banks that borrow more from the central bank is stronger, the availability of central bank funding may have mitigated the shock effects. This assumption is supported by the fact that the difference in response of lending growth and (in most instances) loan rates to wholesale funding shocks between high versus low borrowing banks is not significant. Central bank funding partly substituted the fall in wholesale funding during the crisis. Consequently, the central bank shielded banks in stressed countries to some extent from the effects of shocks in wholesale funding markets.

This substitution effect is illustrated by a simple model, which regresses the ratio of central bank funding over total assets (CB_bor_t) on 12 lags (p = 12) of variable *MFI*,

$$CB\_bor_t = \beta_0 + \beta_1\, MFI_{t-1} + \beta_2\, MFI_{t-1} + \ldots + \beta_p\, MFI_{t-p} + \varepsilon_t \qquad (6)$$

The estimations shown in Table 4 suggest that banks tend to borrow more from the central bank after an adverse shock in the interbank market (the coefficients of *MFI* are negative). This result indicates that central bank funding substitutes interbank funding. The coefficients of *MFI* of high borrowing banks are more significant and have higher values compared to the coefficients of low borrowing banks. Hence, the former sub-sample of banks borrows more from the Eurosystem in response to a fall in interbank funding than the latter sub-sample. We also ran the regression of model 6 with lags of *S_is* as explanatory variables instead of *MFI*. The results in Table 4 show that banks react to a lesser extent by borrowing from the Eurosystem after a shock in securities funding than after a shock in interbank funding (the coefficients of *S_is* are not significant for most lags). This illustrates that central bank borrowing has been foremost a substitute for interbank funding.[12] If we combine this outcome with the finding above that the difference between high and low borrowing banks in lending responses to shocks in *MFI* is not obvious, we conclude that the availability of central bank funding mitigated the impact of wholesale funding shocks on bank lending. In line with Ciccarelli et al. (2013) and Giannone et al. (2012), we find that the extended liquidity operations by the ECB neutralized the effect of the bank lending channel.

[insert Table 4]

6.2 Size and asset composition

The size of the bank is a determining factor for the transmission of wholesale funding shocks. The growth of lending by large banks (i.e. banks with an average main asset value above the full sample median, measured over the whole sample period) responds more strongly to shocks in *S_is* than lending growth of small banks (Figure 9). This difference – cumulatively measured over 12 months - is greater and statistically significant for corporate lending, while the difference is smaller and not statistically significant for household lending. A plausible explanation for the higher sensitivity of lending growth by large banks to *S_is* is that securities issued is a more important funding source for large banks than for small banks (the mean share in main assets of securities issued for large banks is 19% compared to 11% for small banks, see Table 2). The effect on lending growth in response to a shock in *MFI* is larger for small banks, although the difference with large banks is not statistically significant. This also holds for differences in the responses of lending rates with regard to shocks in *MFI* and *S_is* (not reported but available upon request).

[insert Figure 9]

We also investigate whether the asset composition of banks influences the sensitivity of lending growth with regard to shocks in wholesale funding. The risk profile of the asset side is proxied by the holdings of government bonds. We distinguish banks with a share of government bond holdings in its main assets above the median – measured over the whole sample period January 2010 – from banks with government bond holdings below the median. We take the mean before 2010 to exclude the

11 Of the banks in stressed countries 83% is a high central bank borrower, compared to 33% of all banks in non-stressed countries, implying that the subsamples of banks in stressed versus non-stressed countries and high versus low central bank borrowers is related but not identical.

[12] The impulse response functions of a parsimonious panel-VAR model including *MFI*, *S_is and Central Bank borrowing* as endogenous variables confirm that *Central Bank borrowing* reacts significantly and negatively to a shock in wholesale funding, implying that a fall in either *MFI* or *S_is* increases the demand for central bank funding.

period of the European sovereign debt crisis. The impulse responses show that lending by banks with high government bond holdings are more sensitive to shocks in *S_is* and *MFI* than banks with low government bond holdings, although this difference is only statistically significant in the case of the response of *L_nfc* after a shock in *S_is* (Figure 10). The sovereign debt crisis exposed banks with high holdings of peripheral government bonds suddenly to rising investment risk. Our results suggest that this urged those banks to reduce lending in order to de-risk their balance sheet. The difference in the responses of lending rates to shocks in *MFI* and *S_is* is not obvious (not reported but available upon request). Our result is in line with Gennaioli et al. (2014), who find that bond holdings correlate negatively with bank lending during sovereign defaults and this correlation can be explained by bonds acquired in pre-default years.

[insert Figure 10]

6.3 Robustness

In our research we focus on the impact of wholesale funding shocks on lending. However, funding through securities issuance and interbank borrowing represents around one third of total funding of the banks in the full sample (see Table 1). As a robustness check, we test whether inclusion of the other main funding sources (i.e. deposits of non-financial corporations and households, which equal 35% of total funding) would change the model outcomes. We replace variable *Spread* with the variable *D_nfc_hh*, which is the sum of deposits from non-financial corporate firms and households, in models 2 to 5. The impulse responses (not reported but available upon request) show that the outcomes are robust to the inclusion of variable *D_nfc_hh*. The level of the coefficients and the significance of the existing variables hardly change, and the impulse responses are similar to the ones shown in Figures 3 and 4. This also means that lending growth and loan rates continue to show significant positive responses to wholesale funding shocks.

In Section 5 we motivated the ordering of the variables in the p-VAR models. We also performed robustness checks to test the sensitivity of the outcomes for changes in the ordering of the variables. To this end, we put variable *ESI* last in the ordering of models 2-5. In another check, the wholesale funding variables *MFI* and *S_is* are ordered last. The model simulations (not reported but available upon request) show that the outcomes are not sensitive to changing the order of *ESI*; the impulse responses barely change. If the wholesale funding variables *MFI* and *S_is* are ordered last, the impulse responses of loan growth with regard to a shock in *MFI* are no longer significant, while the response of corporate lending growth following a shock *S_is* remains significantly positive.

7. Conclusion

This paper provides empirical evidence on banks' responses to funding liquidity shocks, using data of 181 euro area banks over the period August 2007 to June 2013. The dynamic interrelations among instruments of bank liquidity management are modelled in a panel Vector Autoregressive (p-VAR) framework. Hereby we assess banks' responses to funding liquidity shocks through the liquidity channel (adjustments of loan growth) and the bank interest rate channel (adjustments of lending rates).

Orthogonalized impulse responses reveal that the liquidity channel significantly affects credit supply. Growth in household and corporate lending declines in response to a fall in wholesale funding growth (and vice versa), both with regard to shocks in interbank funding and securities issuance. Corporate lending growth and loan rates are more sensitive to wholesale funding shocks than household lending. The latter respond more strongly to a shock in securities funding than to a shock in interbank funding, which could be explained by the importance of securitisation for the funding of mortgages.

The effects on loan growth in response to a shock in securities funding are greater for banks in stressed countries and for banks with high central bank borrowing, compared to banks in non-stressed countries and banks with low central bank borrowing. However, differences in lending responses to wholesale funding shocks between high and low borrowing banks are not statistically significant, particularly not with regard to shocks in interbank funding, which was mostly substituted by central bank funding. It indicates that central bank funding mitigated the impact of wholesale funding shocks on bank lending.The size of the bank is a determining factor for the transmission of wholesale funding shocks. Loan growth of large banks that are typically more dependent on wholesale funding, responds more strongly to a shock in securities funding than loan growth of small banks. The same result is found with regard to lending by banks with relatively high exposures to government bonds.

All in all the results show that funding liquidity risk is a determining factor in monetary transmission. Moreover there is some evidence that central bank borrowing shielded the lending business of banks from shocks in wholesale funding markets. From this we conclude that the unconventional monetary policy measures of the Eurosystem, notably the unlimited provision of liquidity to banks, has contributed to support private credit growth.

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Appendix A. Variable names and definitions

Balance sheet variables are included as month-on-month growth rates; other variables are included in levels

Assets

L_hh	Loans to households
L_nfc	Loans to corporates (loans with maturity up to one year + loans with maturity over one year)

Liabilities

S_is	Securities issued
MFI	Interbank borrowing

Interest rates

R_lhh	weighted average loan rate households (new business of mortgages, consumer and other, weighted by new business volumes, across all maturities)
R_lnfc	weighted average loan rate corporates (new business of small and large loans, weighted by new business volumes across all maturities)

Financial markets

Spread	Money market spread (spread between 3-month Euro Interbank Offer Rate (Euribor) and overnight Euro Interbank Offer Rates (Eonia) swap index), in basis points

Credit demand

ESI	The Economic Sentiment Indicator (ESI) is a country-specific composite indicator made up of five sectoral confidence indicators with different weights. The ESI is calculated as an index with mean value of 100 and standard deviation of 10 over a fixed standardised sample period. Source: European Commission.

TABLES

Table 1. Balance sheet statistics

Percentage of main assets

	Full sample				*Stressed countries*				*Non-stressed countries*			
	Mean	Median	Std. Dev.	N	Mean	Median	Std. Dev.	N	Mean	Median	Std. Dev.	N
Assets												
Loans to HH (L_hh)	25	24	17	12272	27	26	14	8209	24	21	19	4063
Loans to NFC (L_nfc)	21	19	14	12272	29	28	13	8209	18	15	13	4063
Loans to MFI	16	12	13	12272	10	7	9	8209	19	15	14	4063
Gov Securities	6	4	6	12272	5	4	4	8209	6	4	6	4063
Liabilities												
Deposits (HH+NFC)	35	33	22	12272	34	32	15	8209	35	37	25	4063
Borrowing MFI (MFI)	17	14	14	12272	13	8	14	8209	19	17	14	4063
Securities issued (S_is)	15	12	16	12272	14	11	13	8209	16	12	17	4063
Capital and Reserves	7	7	5	12272	10	9	6	8209	6	6	3	4063
Eurosystem borrowing	3	0,2	5	12272	5	2	7	8209	1	0	3	4063

Note: Means do not sum to 100 as only a subset of balance sheet items is shown.
Asset items not shown are assets vis-à-vis non euro area counterparties, government lending, private sector securities , shares and other equity, mfi securities, loans to other non-MFI financial institutions.
Liability items not shown are liabilities vis-à-vis non euro area counterparties, government deposits.

	High Eurosystem borrowing				*Low Eurosystem borrowing*			
	Mean	Median	Std. Dev.	N	Mean	Median	Std. Dev.	N
Assets								
Loans to HH (L_hh)	24	23	15	6203	26	26	19	6069
Loans to NFC (L_nfc)	25	25	13	6203	18	15	14	6069
Loans to MFI	12	10	9	6203	20	16	15	6069
Gov Securities	6	5	5	6203	5	3	6	6069
Liabilities								
Deposits (HH+NFC)	33	32	19	6203	36	41	25	6069
Borrowing MFI (MFI)	16	12	14	6203	18	16	14	6069
Securities issued (S_is)	15	12	14	6203	16	11	18	6069
Capital and Reserves	8	7	5	6203	7	6	4	6069
Eurosystem borrowing	5	3	6	6203	0,5	0	2	6069

	Small banks				*Large banks*			
	Mean	Median	Std. Dev.	N	Mean	Median	Std. Dev.	N
Assets								
Loans to HH (L_hh)	32	31	17	5996	18	15	15	6276
Loans to NFC (L_nfc)	25	25	15	5996	18	16	12	6276
Loans to MFI	13	11	11	5996	19	15	15	6276
Gov Securities	5	3	6	5996	6	5	5	6276
Liabilities								
Deposits (HH+NFC)	44	46	20	5996	26	24	21	6276
Borrowing MFI (MFI)	17	13	15	5996	18	15	15	6276
Securities issued (S_is)	11	6	14	5996	19	16	17	6276
Capital and Reserves	8	7	5	5996	7	6	4	6276
Eurosystem borrowing	2	0	4	5996	3	0,8	6	6276

	Low Capital (before 2010)				*High Capital (before 2010)*			
	Mean	Median	Std. Dev.	N	Mean	Median	Std. Dev.	N
Assets								
Loans to HH (L_hh)	24	23	20	6014	25	24	14	5945
Loans to NFC (L_nfc)	17	14	13	6014	26	25	13	5945
Loans to MFI	18	15	14	6014	14	10	12	5945
Gov Securities	5	3	5	6014	6	5	6	5945
Liabilities								
Deposits (HH+NFC)	31	26	26	6014	38	38	18	5945
Borrowing MFI (MFI)	18	16	13	6014	16	11	15	5945
Securities issued (S_is)	20	15	19	6014	12	9	11	5945
Capital and Reserves	5	5	2	6014	10	9	5	5945
Eurosystem borrowing	2	0	4	6014	3	0,6	6	5945

Table 2. Summary statistics of regression variables

Full sample

		Mean	Median	Std. Dev.	N
Monthly Growth rates (in %)					
Borrowing from MFI	*MFI*	-0,32	-0,10	21,66	12087
Securities issued	*S_is*	-0,68	0,00	7,06	10879
Lending to NFC	*L_nfc*	0,31	0,14	3,94	12091
Lending to HH	*L_hh*	0,14	0,11	2,70	12091
Level variables					
ESI (index, base=100)	*ESI*	93.42	95.5	13.98	12567
Spread (in basis points)	*Spread*	49.3	37.94	33.34	12851
Lending rate to NFC (in %)	*R_lnfc*	4.79	4.59	2.05	9798
Lending rate to HH (in %)	*R_lhh*	6.89	6.63	2.82	10067

Table 3. Cumulative impulse responses

Responses in percentage points, cumulated over 12 months, full sample

	Shock		
	S_is	MFI	Spread
Response			
L_nfc	0,16	0,19	0,06
L_hh	0,05	0,01	-0,49
R_lnfc	-0,01	-0,01	0,20
R_lhh	-0,21	0,00	0,10

Table 4. Estimation result central bank borrowing model
Dependent variable is Central Bank borrowing as a percentage of main assets

	High CB borrowers		*Low CB borrowers*	
	Coeff		Coeff	
MFI_t	-0.03079	***	-0.00753	***
MFI_{t-1}	-0.02151	***	-0.00612	***
MFI_{t-2}	-0.01915	***	-0.00424	***
MFI_{t-3}	-0.02613	***	-0.00483	***
MFI_{t-4}	-0.02202	***	-0.00376	***
MFI_{t-5}	-0.02524	***	-0.00319	***
MFI_{t-6}	-0.02164	***	-0.00240	**
MFI_{t-7}	-0.02142	***	-0.00214	**
MFI_{t-8}	-0.02036	***	-0.00187	*
MFI_{t-9}	-0.01482	***	-7.93e-02	
MFI_{t-10}	-0.01600	***	-9.19e-04	
MFI_{t-11}	-0.01631	***	-7.14e-04	
MFI_{t-12}	-0.07700	***	-4.07e-04	
constant	5.1635	***	0.360244	***
R2-within	0.0570		0.0198	
number of obs	5013		4892	
number of banks	89		90	

	High CB borrowers		*Low CB borrowers*	
	Coeff		Coeff	
S_t	-0.023318	**	0.0039808	
S_{t-1}	-0.0196316	*	0.0019753	
S_{t-2}	-0.0194431	*	0.0038645	
S_{t-3}	-0.0141382		0.0026137	
S_{t-4}	-0.0150291		0.0035761	
S_{t-5}	-0.010161		0.0052276	*
S_{t-6}	-0.0188448	*	-0.0022911	
S_{t-7}	-0.0257802	**	-0.0033766	
S_{t-8}	-0.0263404	**	0.000718	
S_{t-9}	-0.020908	*	-0.0008943	
S_{t-10}	0.002974		0.0003753	
S_{t-11}	-0.0017298		-0.002149	
S_{t-12}	-0.0006506		-0.0008567	
constant	5.056591	***	0.3898403	***
R2-within	0.0094		0.0025	
number of obs	4445		4414	
number of banks	80		83	

Explanatory note. Fixed bank effects included (not reported).
***, **, * denote p-values less than or equal to 1%, 5%, 10%, respectively.

FIGURES

Figure 1. Money market spread euro area
3 months Euribor spread, basis points

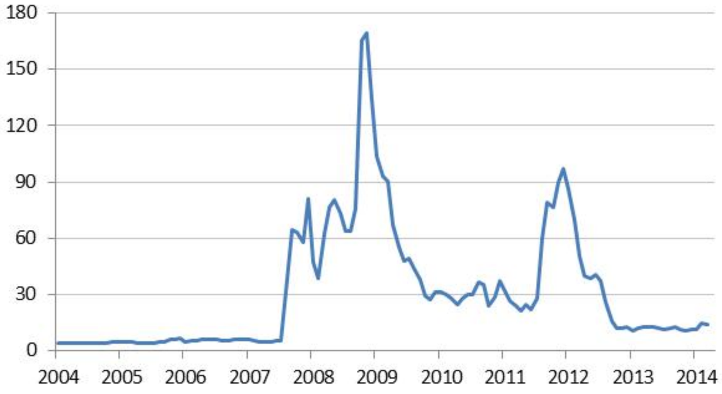
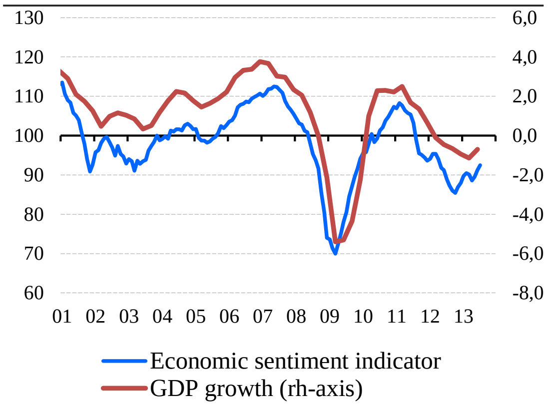
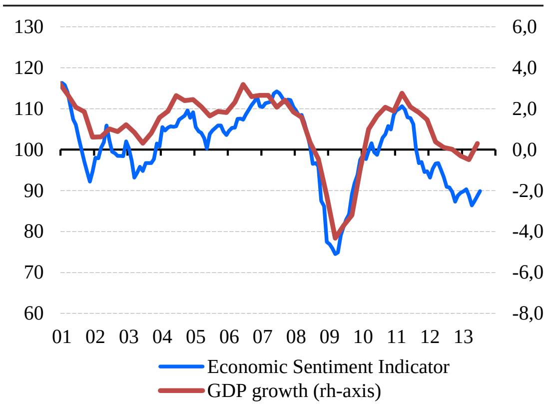


Figure 2. Monthly Economic Sentiment Indicator and quarterly real GDP growth

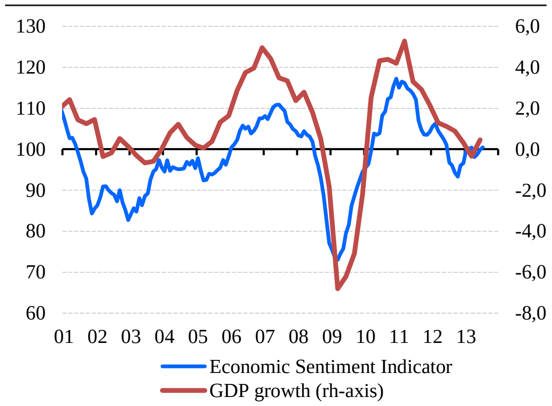
ESI & GDP growth euro area
ESI (100 is base value), GDP in yoy percentage changes



ESI & GDP growth France
ESI (100 is base value), GDP in yoy percentage changes



ESI & GDP growth Germany
ESI (100 is base value), GDP in yoy percentage changes



ESI & GDP growth Italy
ESI (100 is base value), GDP in yoy percentage changes

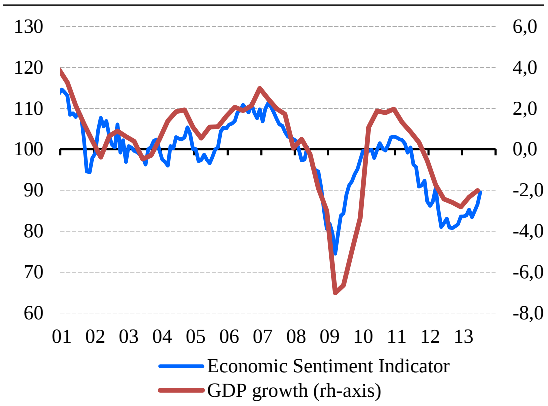


Figure 3. Impulse responses, Liquidity channel, full sample, selection of outcomes from models 2, 3, 4 5.

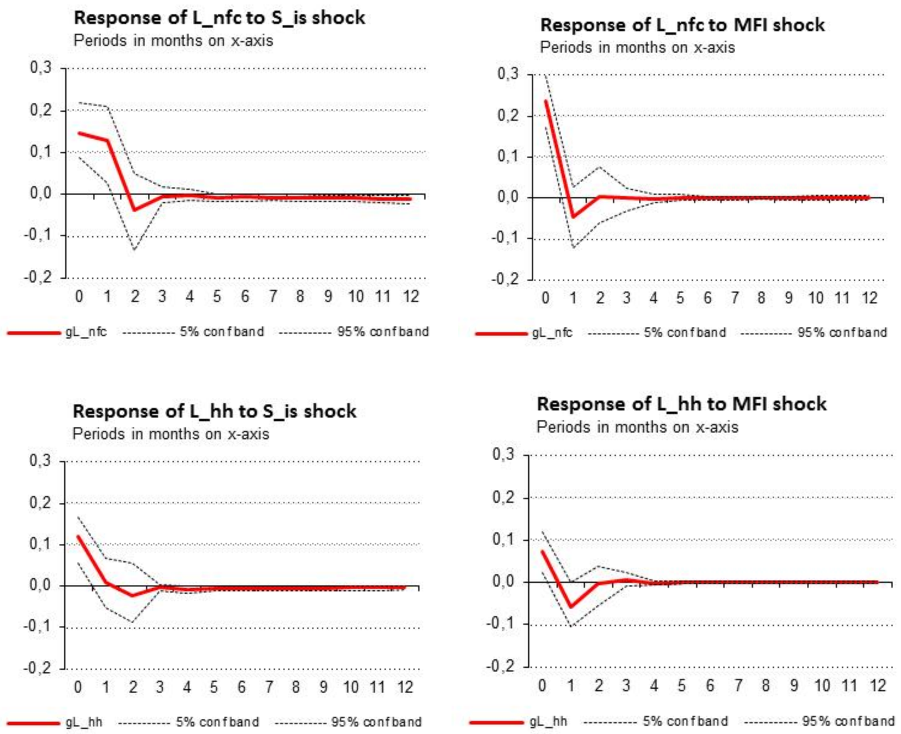


Figure 4. Impulse responses, Bank interest rate channel, full sample, selection of outcomes from models 2, 3, 4 5.

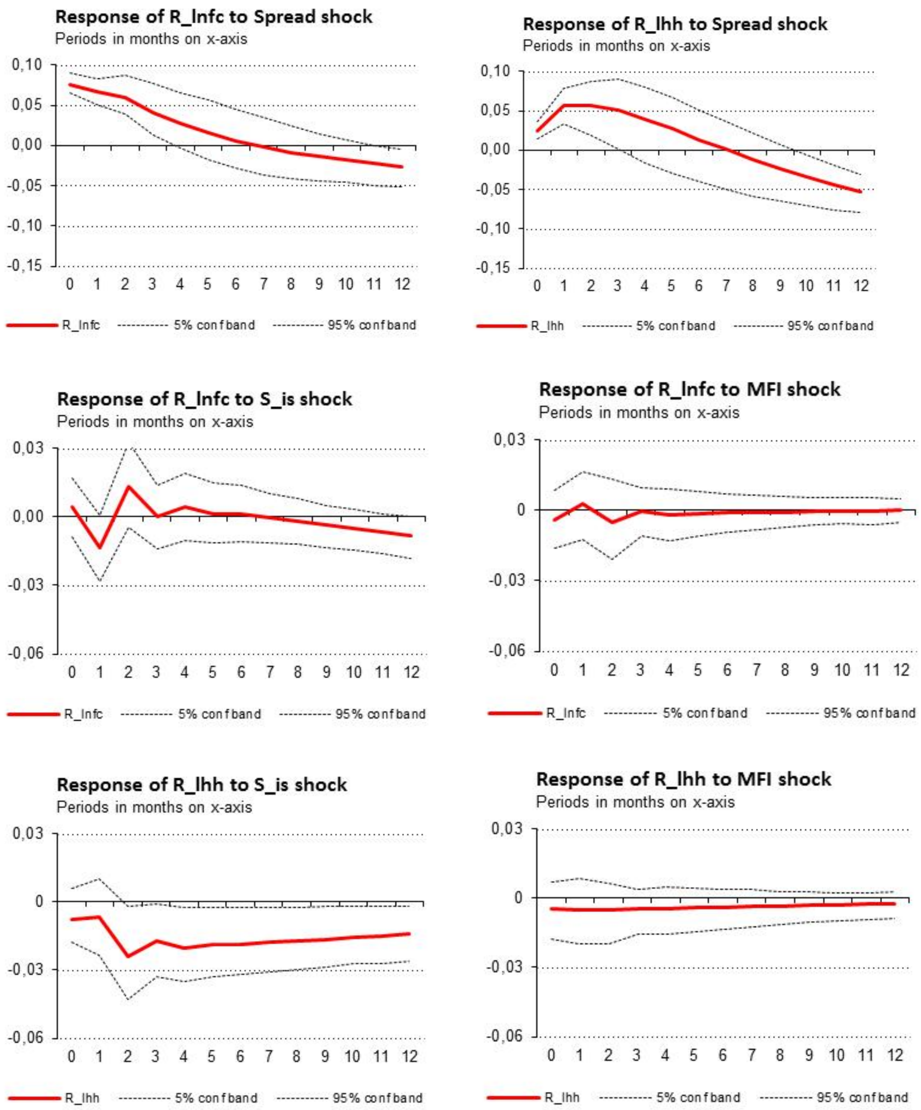


Figure 5. Impulse responses of lending volumes of banks in stressed versus non-stressed countries

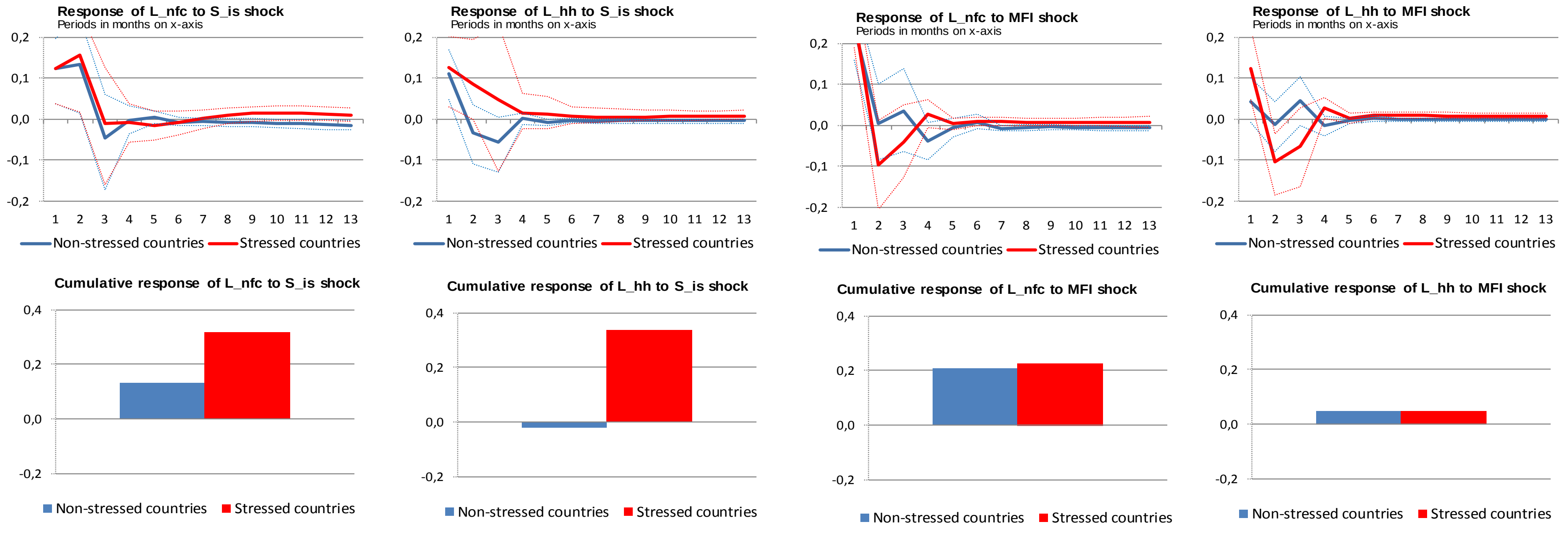


Figure 6. Impulse responses of lending rates of banks in stressed versus non-stressed countries

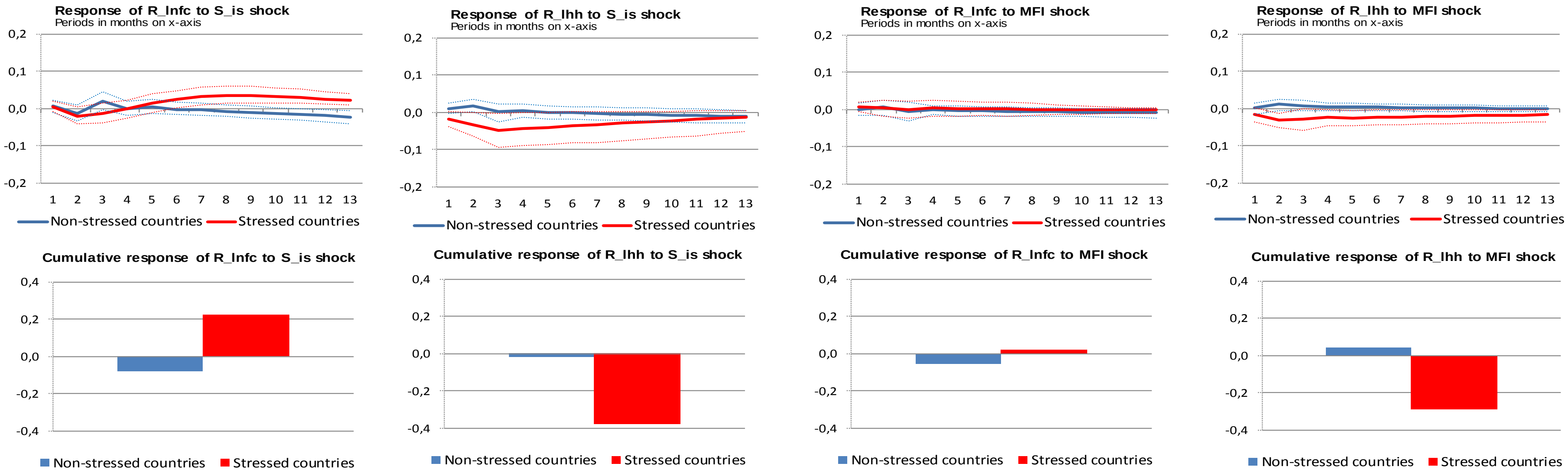


Figure 7. Impulse responses of lending volumes by high versus low Central Bank borrowing banks

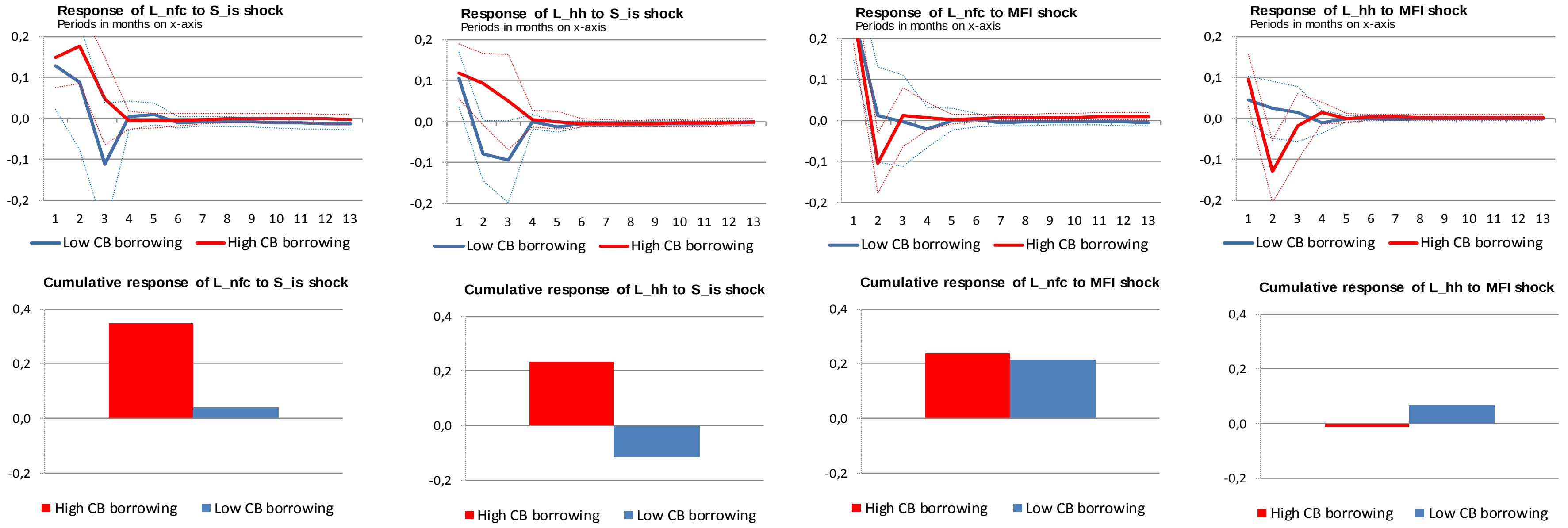


Figure 8. Impulse responses of lending rates by high versus low Central Bank borrowing banks

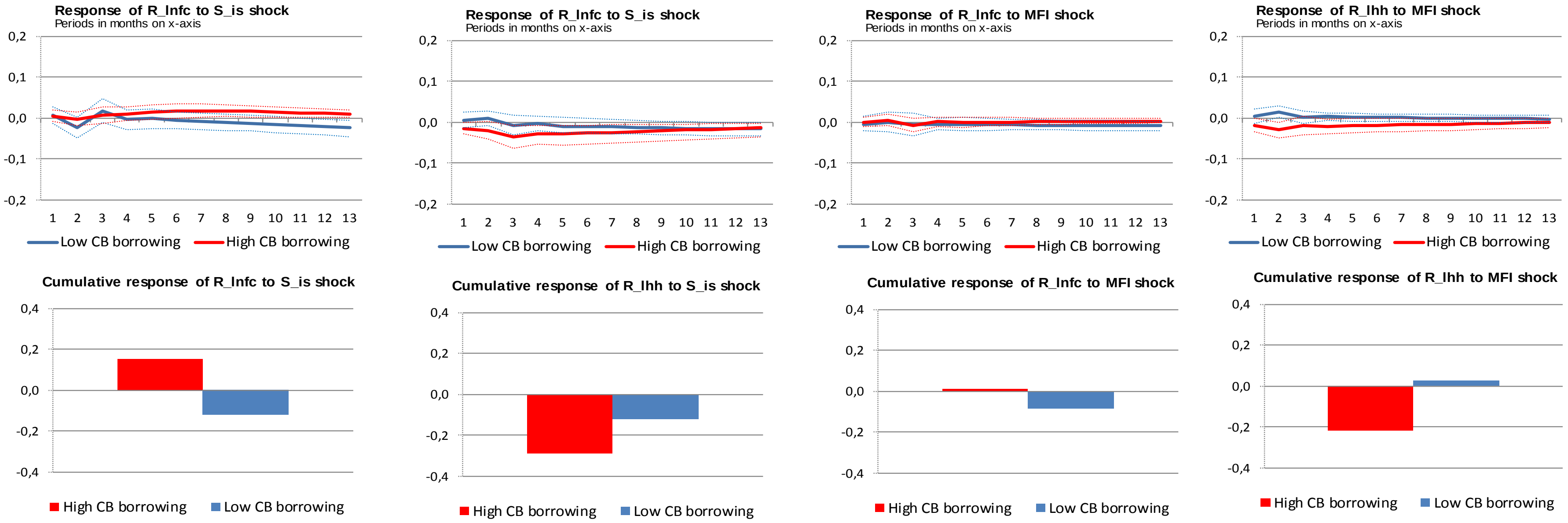


Figure 9. Impulse responses of lending volumes by small versus large banks

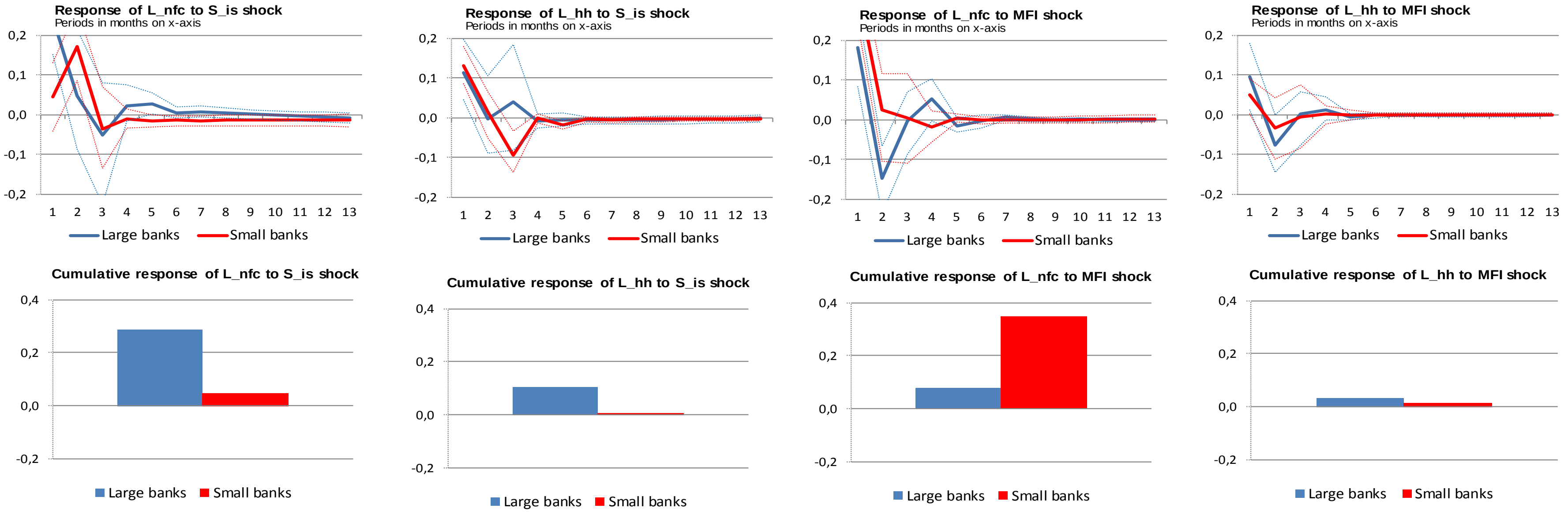
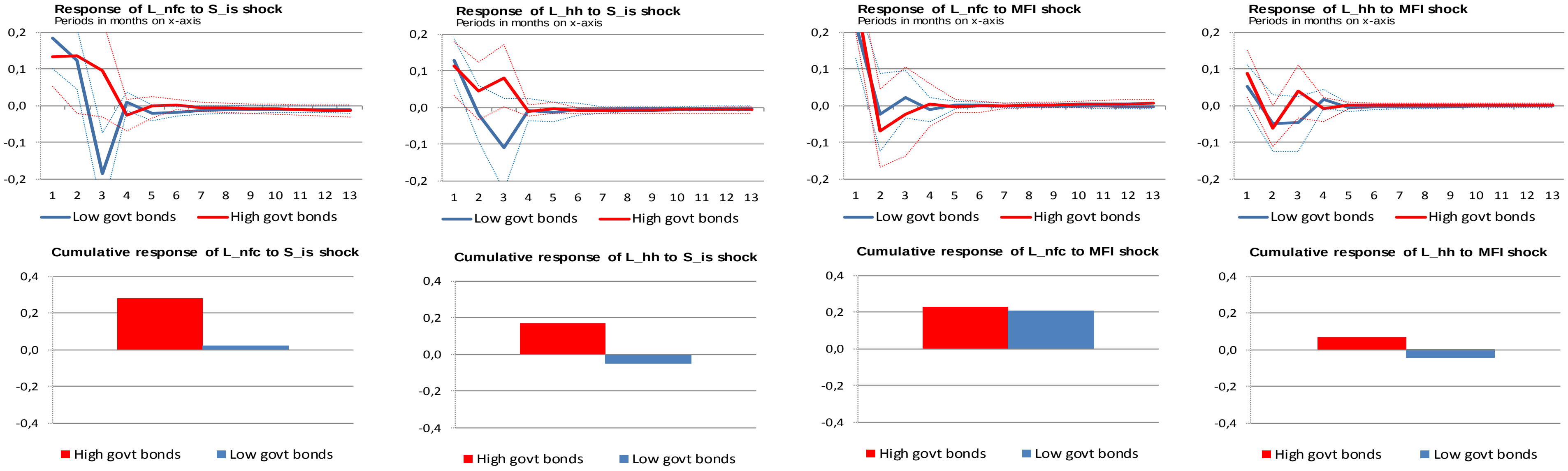


Figure 10. Impulse responses of lending volumes by banks with high versus low government bond holdings



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